Groundwater/Surface Water Interactions in the Upper Sammamish River: A Preliminary Analysis

Abstract

Due to excessive temperatures, three segments of the Sammamish River are included on the federal Clean Water Act 303(d) list for Washington State impaired waters. Mini-piezometers were installed at nine locations along the upper six miles of the river in August 2001 to observe groundwater/surface water interactions during the fall low-flow period. Seven-foot long mini-piezometers were installed in the streambed to a depth of four to five feet below the sediment-water interface with openings in the bottom six inches. The difference between the water height inside and outside the piezometer was used as an indicator of flow direction in the immediate area.

Measurements collected monthly in the fall of 2001 indicate that groundwater discharged to the river at eight of nine sites on all but one date. The flow direction at the site near Leary Way was consistently from the river to the streambed, contrary to geologic indications of discharge from the adjacent Bear Creek Alluvial Valley. The groundwater flow direction at the Marymoor Park site appeared to reverse slightly in November 2001, from discharging to the river in previous months to recharging the aquifer. Specific conductivity generally increased from upstream to downstream sites, indicating net discharge of higher conductivity groundwater along the study reach.

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Introduction

The Sammamish River flows north from the outlet of Lake Sammamish to Lake Washington at Kenmore in King County, Washington (Figure 1). Three segments of the 14-mile river are listed for exceedances of temperature standards on the federal Clean Water Act 303(d) list for Washington State. Chinook and sockeye salmon travel through the Sammamish River. Most of the salmon return to the Issaquah Hatchery above Lake Sammamish, but some also spawn naturally in the basin (Martz et al., 1999).

The river has been altered dramatically since settlers first came to the Sammamish Valley in the mid-1800s. The densely forested valley was cleared for agriculture in the early twentieth century, and the river contained extensive meanders and oxbows. The estimated original length of the river, 30 miles, is more than twice the current length (Martz et al., 1999). When the Lake Washington Ship Canal and Ballard Locks were completed in 1916, the level of Lake Washington was lowered almost nine feet. The level of Lake Sammamish consequently decreased by six feet, causing the adjoining Sammamish River to become more incised in its mainly artificial channel while conveying nearly the same flows.

Dredging of the river to straighten the channel and enhance navigation in the early 1900s is believed to have destroyed most of the river's salmon spawning habitat (Martz et al., 1999). All fisheries in the basin except resident trout were depleted by the early 1950s. The river was already nearly as straight as it is today when the most recent U.S. Army Corps of Engineers (ACOE)/King County flood control project began in the 1950s. Most of the remaining abandoned river channels and wetlands were removed as part of the ACOE/King County project, and riparian (willow) vegetation was replaced with grass. Loss of riparian canopy along the river has probably had the greatest impact on temperature conditions.

Present land use in the river corridor is mainly agricultural and recreation (Marymoor Park, a bike trail, and golf course). The watershed has changed from forested to urban and residential uses over the past 30-50 years with especially rapid development in the past 20 years in and around the city of Redmond.

The King County Department of Natural Resources & Parks (KC DNRP) is conducting a detailed hydrogeologic study of the Sammamish River area in order to better understand the surface water/groundwater relationships and related temperature conditions (Johnson, 2001).

The purpose of the study described in this report was to provide data for the larger KC DNRP hydrogeologic study indicating whether groundwater is entering the river (gaining) or leaving the river (losing) during low-flow conditions when the river temperature is typically highest. The method used to determine flow direction involved comparison of water levels of instream mini-piezometers with water elevations in the river. Differences in temperature and specific conductivity also were compared and used as indicators of groundwater/surface water interaction.

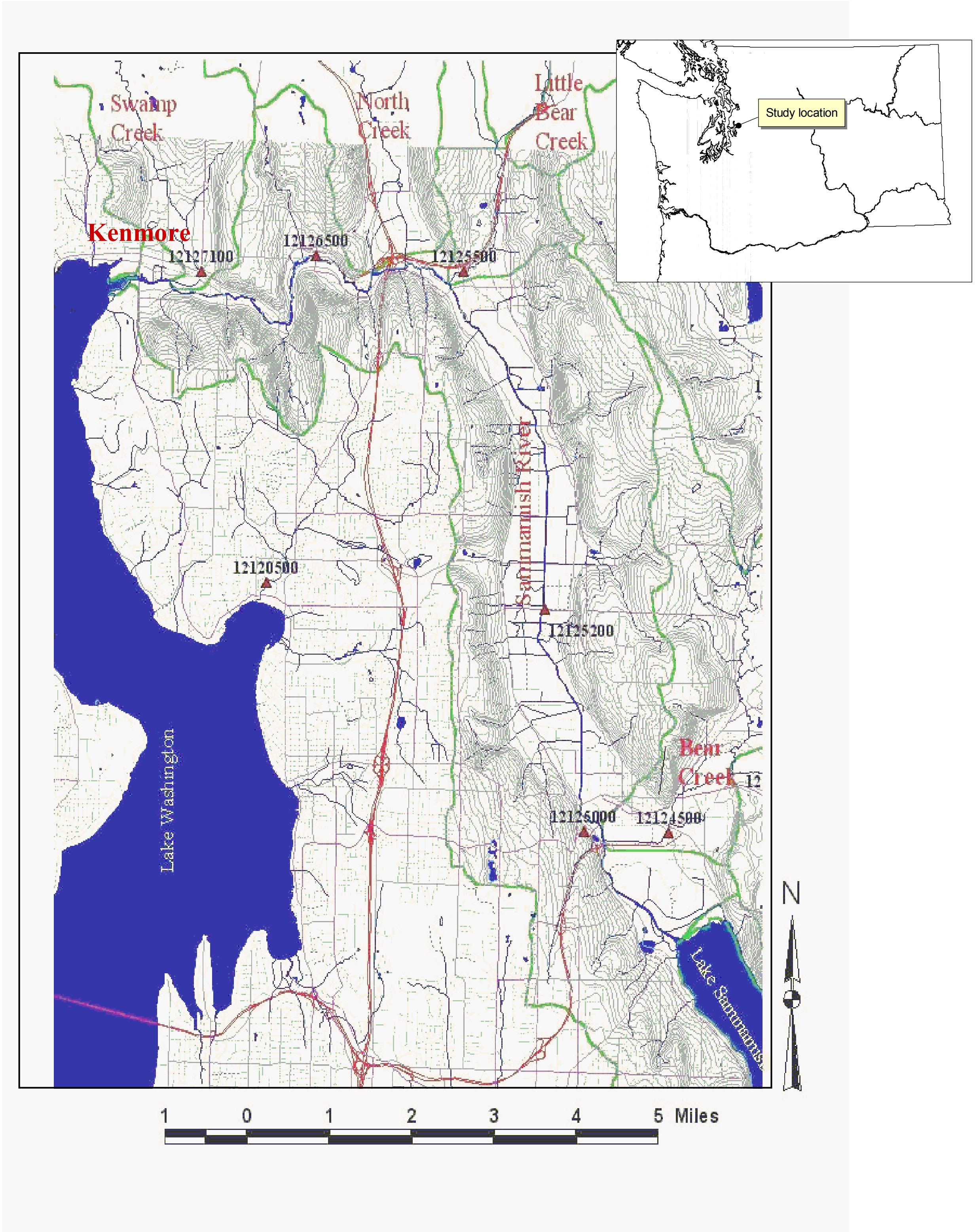


Figure 1. The Sammamish River Valley area and local USGS gaging stations (from KC DNRP, 2001).

Hydrology and hydrogeology

The average annual flow in the Sammamish River is 311 cubic feet per second (cfs) based on streamflow records for 1965-2000 as measured at Woodinville (USGS Gage No. 12125200). The lowest flow in the river is usually about 70 cfs and typically occurs in August. Most of the flow in the river is from surface water: Lake Sammamish, Bear Creek, and other tributaries. However, a modeling analysis of the historical streamflow records for the watershed indicates that 65-85% of summer flow in Bear Creek and tributaries has been from baseflow derived from groundwater (Sinclair and Pitz, 1999). It is not known if recent rapid urbanization has altered streamflow patterns, because the records used in the analysis are mainly from earlier years.

Runoff estimates for the largest tributary to the river, Bear Creek, indicate that it contributes about 25% of the flow to the river. Water budget calculations indicate that groundwater flow beneath the creek channel may also account for about 10 cfs, a significant amount during the summer (KC DNR, 2001).

The main aquifers interacting with the river are the alluvium and Vashon recessional outwash aquifers beneath the river and tributary valleys (Figure 2). Much of the watershed is covered with Vashon till which allows only limited infiltration of precipitation (Figure 3). Local upland aquifers cover some of the topographic ridges surrounding the valley watershed and are comprised of Vashon recessional and advance outwash and in some places more permeable till. These local aquifers may recharge the alluvial aquifers along the valley walls (Redmond – Bear Creek Valley Ground Water Advisory Committee, 1999).

Bear Creek is a major tributary to the Sammamish River, and the Bear Creek Valley is a major contributor to the river/aquifer system. The alluvial aquifer shown in Figure 2 actually consists of more alluvial material at the mouth but is underlain by a thicker layer of Vashon recessional outwash material that makes up most of the upper Bear Creek Valley. The Bear Creek Aquifer adjoins the aquifer beneath the Sammamish River. Deeper aquifers, referred to as the sea level aquifers and the regional aquifer, are separated for the most part from the alluvial aquifers by low permeability layers and therefore do not interact significantly with the overlying aquifers.

Temperature measurements have been collected for the Sammamish River by the ACOE to model temperature changes along the river (KC DNR, 2001). The ACOE also conducted Forward Looking Infrared (FLIR) remote sensing surveys on the river on September 2, 1999 and March 23, 2000 (McIntosh et al., 2000) which indicated potential areas where groundwater inflow may be significant.

Methods

Long, narrow metal pipes with small openings at the bottom, called mini-piezometers, were installed in shallow riverbank areas at nine sites in the upper end of the river (Figure 4). Mini-piezometer measurements were made four times between August and November 2001,

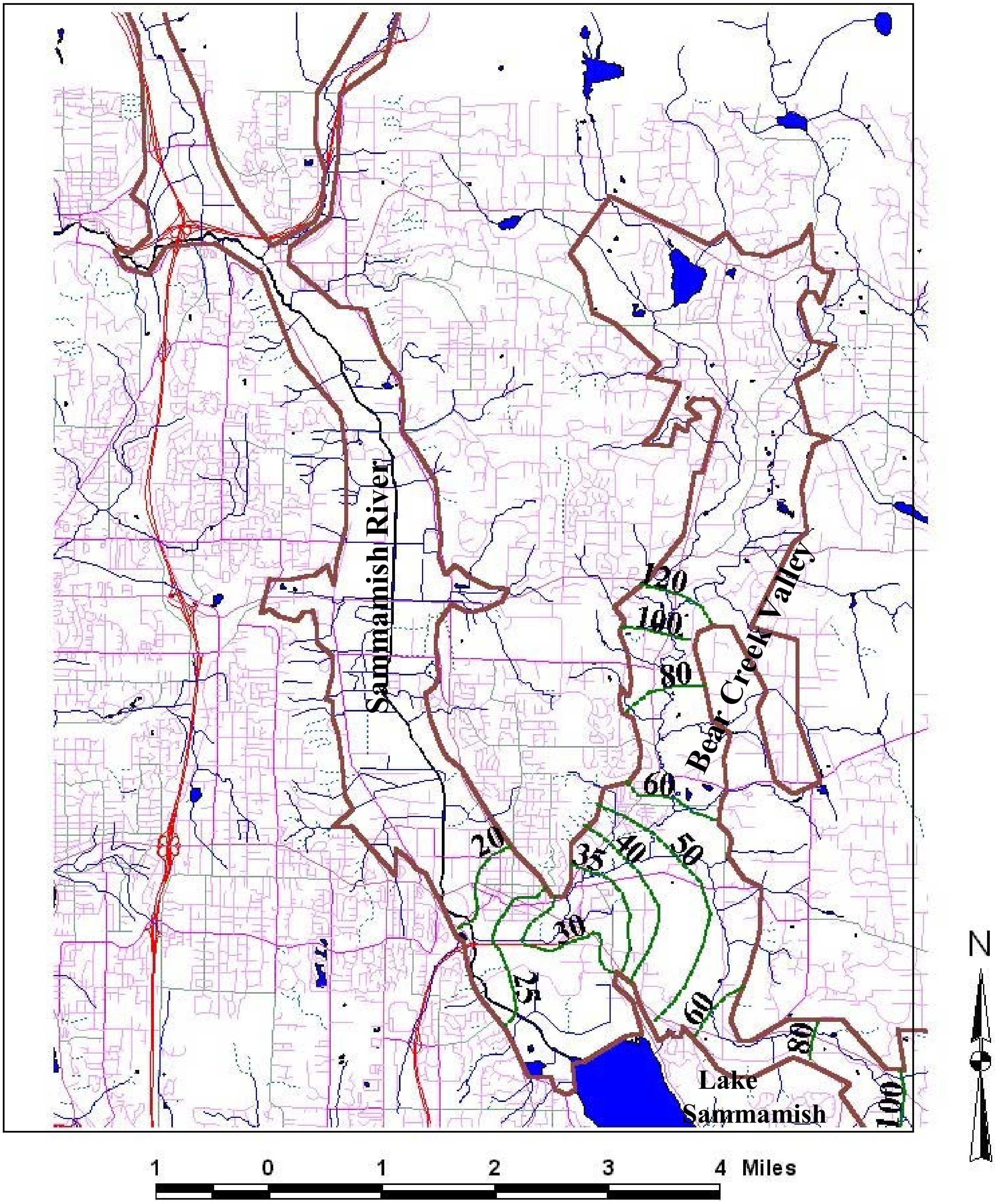
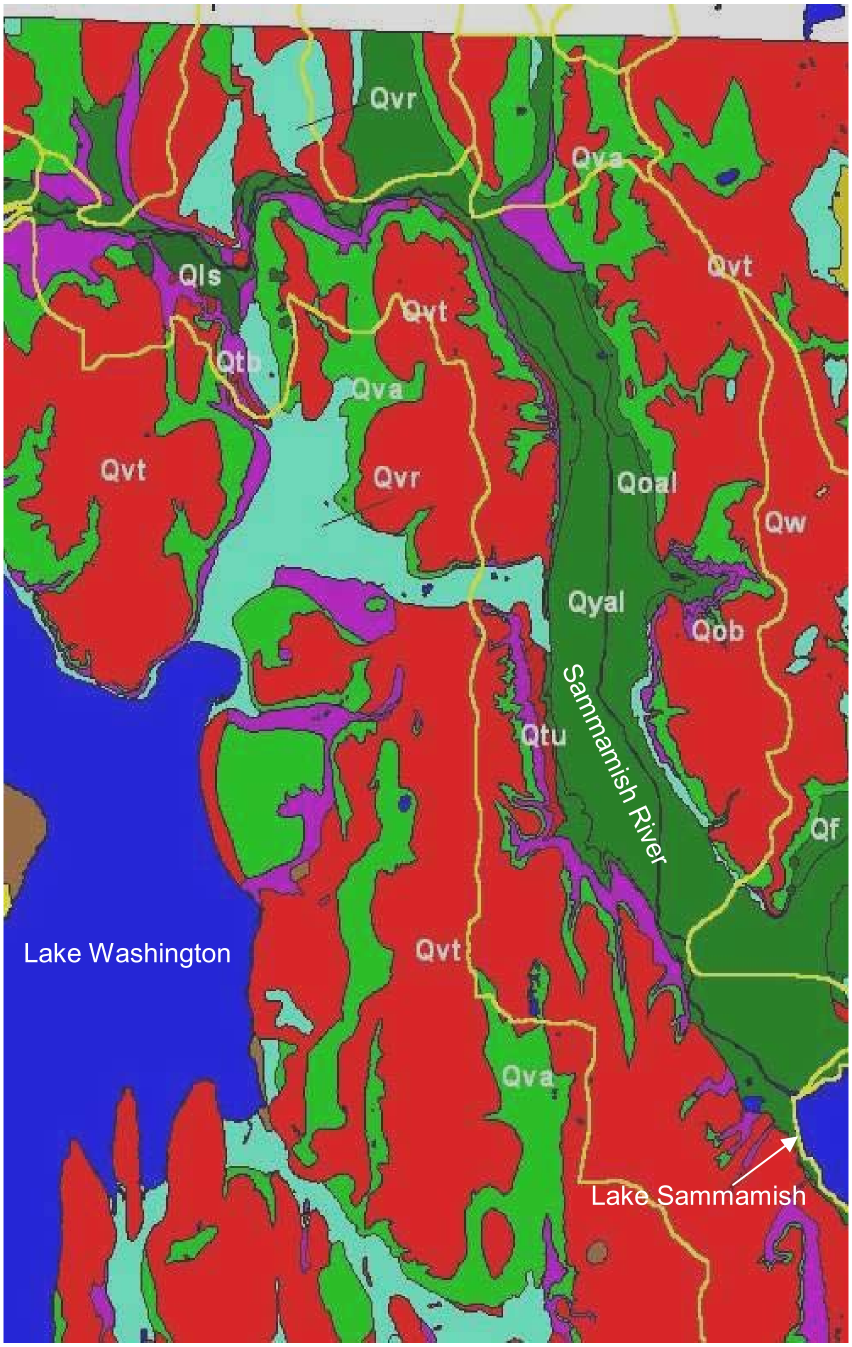


Figure 2. Approximate extent of the alluvial aquifer in the Sammamish River area and elevations in feet from National Geodetic Vertical Datum of 1929 (from Johnson, 2001).



Qw:	Wetland deposits	Qvt:	Vashon till
Qyal:	Younger alluvium	Qva:	Vashon advance outwash
Qoal:	Older alluvium	Qob:	Olympia beds
Qf:	Alluvial fan deposits	Qtu:	Till, undifferentiated
Qvr:	Vashon recessional outwash	Qtb:	Transitional beds

Figure 3. Surficial geology of the study area (from Johnson, 2001).

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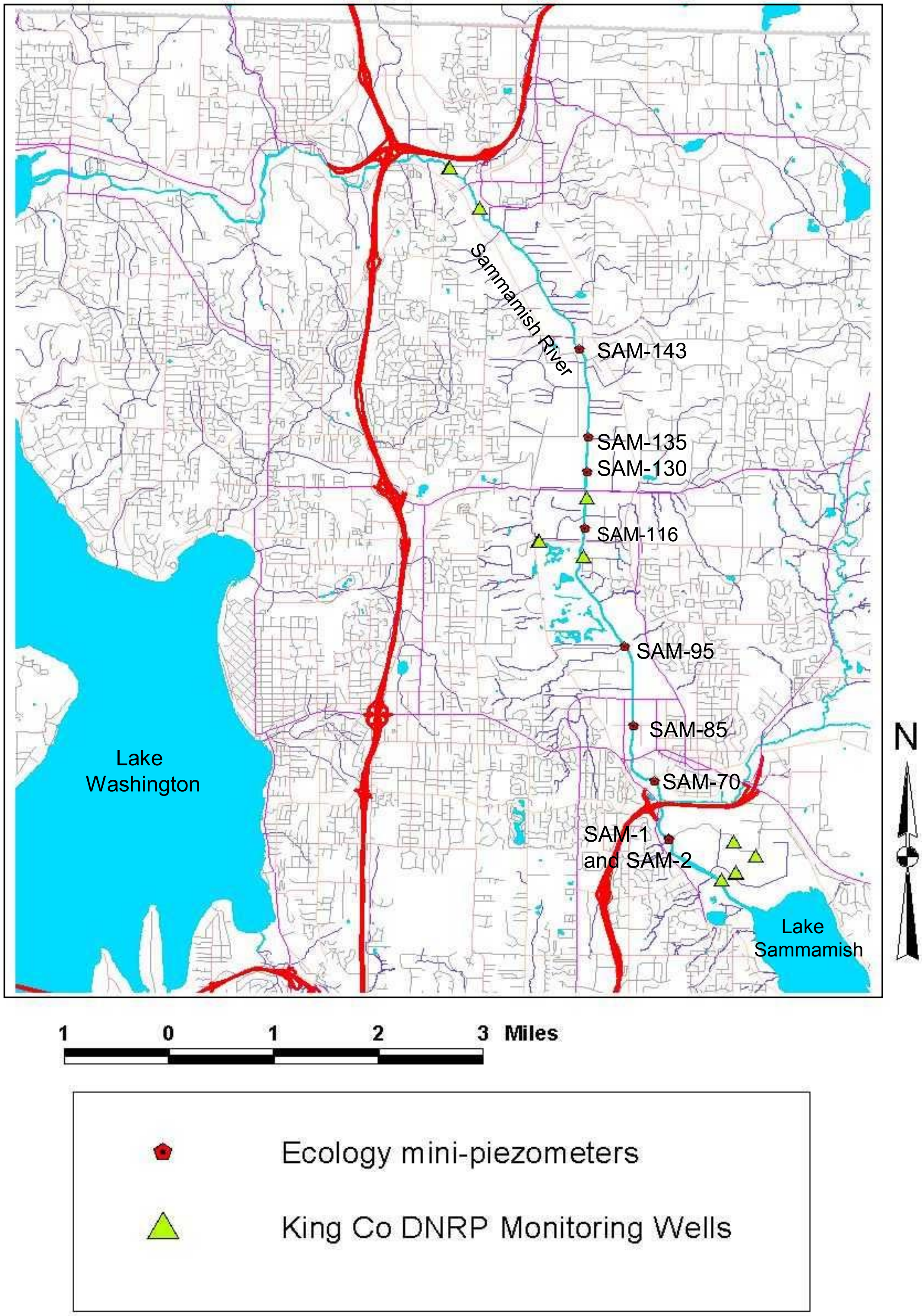

Figure 4. Mini-piezometer locations used in this study and monitoring wells installed for the King County Department of Natural Resources and Parks study (Johnson, 2003).

to determine whether groundwater was discharging to the river or if river water was recharging the aquifer. If the water level inside the mini-piezometer was higher than the outside river stage, then groundwater was assumed to be discharging to the river. If the river stage exceeded the groundwater level inside the mini-piezometer, then river water was assumed to be recharging the aquifer.

An attempt was made to site mini-piezometers in areas where groundwater discharge was suspected, based on previous FLIR temperature studies (KC DNR, 2001 and McIntosh et al., 2000). Figure 5 shows the mini-piezometer locations relative to the FLIR temperature profile. Ease of access and aereal coverage were also considered in site selection for mini-piezometers. Locations where bridges crossed the Sammamish River bicycle path provided the easiest access down the riverbank. Therefore, six of the nine mini-piezometers were installed near bridges as shown in Figure 4 (SAM-70, SAM-85, SAM-116, SAM-130, SAM-135, and SAM-143). Two sites were located on either side of the bridge at Marymoor Park, and one site was on the west bank near the Overlake Church. Due to access difficulties, the lower eight miles of the river were not characterized during this study despite indications of groundwater discharges.

The mini-piezometers consisted of seven-foot long, ½-inch diameter galvanized steel pipes crimped closed on the bottom. Small holes (3/16-inch diameter) were drilled into the bottom six inches of the pipe to allow water to enter. The samplers were hand-driven into the streambed using a fencepost driver until the top of the sampler was above the water surface and the bottom was about five feet below the bottom of the riverbed. Each mini-piezometer was equipped with a screw-on cap to protect the pipe during installation. The piezometer remained capped except when samples were collected. Each piezometer was developed initially using a peristaltic pump to ensure a good hydraulic connection with the streambed sediments. Water level measurement procedures for the mini-piezometers and the river stage are described in the Appendix.

A hand-held global positioning system (GPS) receptor was used to establish the latitude and longitude of each mini-piezometer. The horizontal accuracy of the GPS instrument is about 50 feet. Table 1 shows the location and construction details for each mini-piezometer.

A private utilities locator service inspected each site prior to mini-piezometer installation in order to mark buried lines and prevent accidental breaks in above- and below-ground utilities when installing the mini-piezometers.

Measurements for surface water temperature and conductivity were made at the same time and location in the river as for the mini-piezometer. Temperature and conductivity were measured in the streambed water by pumping with a peristaltic pump from the bottom end of the piezometer into a ½-liter container holding the Geoprobe temperature and conductivity probe. Temperature and conductivity of the groundwater were monitored until measurements had stablized to within 5% for conductivity and +/- 0.2ºC. Additional details of procedures for temperature and conductivity measurements are described in the Appendix. The mini-piezometers were left in place at the end of the study for possible future use by the KC DNR.

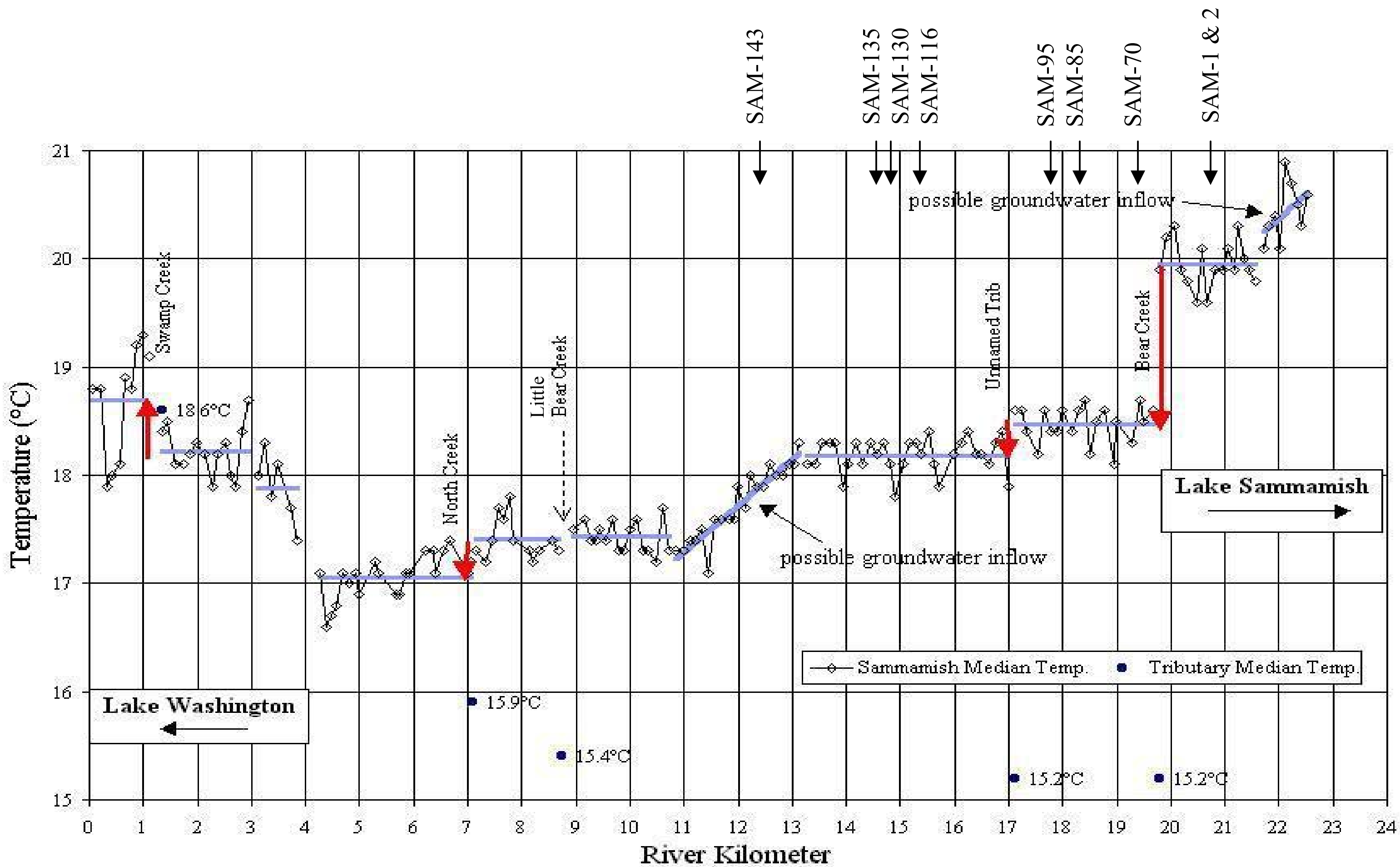

Figure 5. Temperature profile in the Sammamish River based on FLIR data with approximate mini-piezometer locations shown along the top (from KC DNRP, 2001 and McIntosh et al., 2000).

Table 1. Sammamish River piezometer locations and construction information.

Map ID	Piezometer location	Latitude (dms.s)	Longitude (dms.s)	River Mile[1] (mile)	Piezometer stick-up above streambed (feet)	Piezometer depth below streambed (feet)
SAM-1	Marymoor Park Bridge -- east bank	47 39 45.6 N	122 07 23.9 W	20.9	2.0	5.0
SAM-2	Marymoor Park Bridge -- west bank	47 39 44.0 N	122 07 25.0 W	20.9	2.0	5.0
SAM-70	North of Leary Way behind Riverside Apts -- east bank	47 40 16.4 N	122 07 43.3 W	20.2	2.0	5.0
SAM-85	100 feet south of 85th Ave. bridge, Redmond -- east bank	47 40 41.6 N	122 07 55.9 W	19.6	2.6	4.4
SAM-95	Overlake Church -- west bank	47 41 21.5 N	122 08 02.8 W	19.2	2.1	4.9
SAM-116	100 yards north of NE 116th St. bridge -- east bank	47 42 22.0 N	122 08 29.5 W	17.7	2.8	4.3
SAM-130	0.2 mile north of NE 124th St. bridge -- east bank	47 42 50.2 N	122 08 28.5 W	17.2	1.8	5.2
SAM-135	0.5 mile north of NE 124th St. bridge -- east bank	47 43 07.9 N	122 08 28.0 W	17.1	2.2	4.8
SAM-143	0.1 mile south of NE 145th St. bridge -- east bank	47 43 52.6 N	122 08 35.1 W	15.8	2.6	4.4

[1] Miles upstream of the river mouth.

Temperature loggers were fastened with wire at the base of three mini-piezometers just below the sediment surface (SAM-1, SAM-116, and SAM-130). The temperature data were intended to provide an additional basis for comparison between sites. Temperature loggers were programmed to record measurements every hour from the date installed, August 9, 2001 for SAM-1 and August 20, 2001 for SAM-116 and SAM-130, until removal on November 9, 2001.

Data analysis method

The vertical hydraulic gradients between the river and the piezometer intakes were calculated using the formula from Simonds and Sinclair (2002):

$i_v = dh/dl$

where: i_v = the vertical hydraulic gradient (L/L)
dh = the difference between the river water level and the mini-piezometer water level (L)
dl = the distance from the stream bed to the midpoint of the piezometer perforations (L)

Positive values for i_v indicate groundwater discharge to the river, while negative values indicate surface water flow into the streambed.

Data quality

The quality of the water level measurements was ensured by duplicating field measurements. If duplicate measurements were not within 0.01 foot, then additional measurements were made until the discrepency between meaurements was within 0.01 foot.

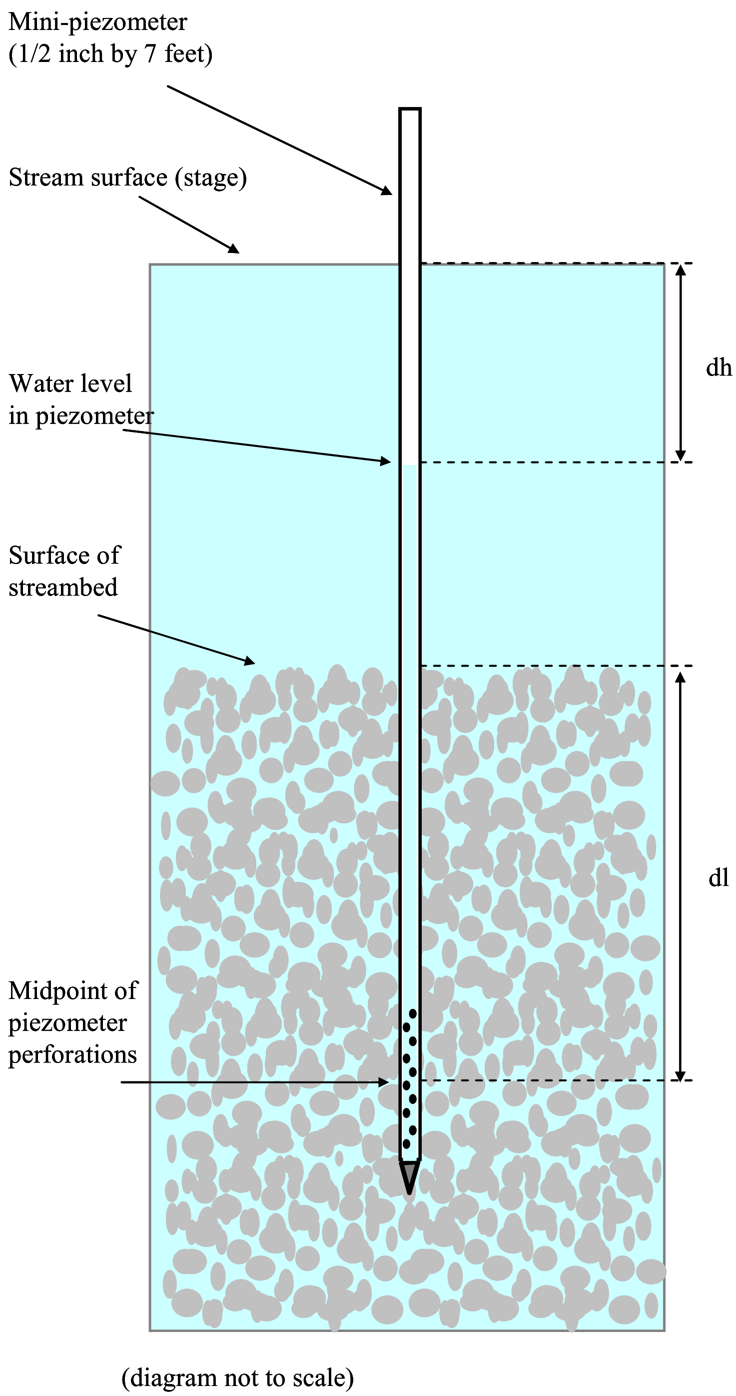

Figure 6. Schematic of instream mini-piezometer installation (from Sinclair, 2001).

Results

Water level measurements

Water level measurements inside the mini-piezometers and in the river are shown in Table 2. When the elevation in the mini-piezometer was higher than the river stage, as indicated by a positive gradient value, then the flow direction at that point was from the groundwater to the river. When the river stage elevation was higher than the mini-piezometer water level, then river water was seeping into the subsurface.

Water elevations in most cases were higher in the mini-piezometers than in the river, indicating groundwater discharge to the river in the immediate vicinity of the piezometer. The differences between surface and groundwater elevations at these sites ranged from 0.05 to 0.37 foot. In contrast, larger differences in water levels at SAM-70 of up to -1.6 feet indicate surface water recharging groundwater on all dates.

The differences at SAM-1 and SAM-2 in November (-0.02 and -0.04 foot) were close to the margin of error of the measurements but indicated possible recharge into the aquifer. In addition to possible flow reversal at SAM-1 and SAM-2 in November, both the river elevation and the groundwater elevation rose by about one foot compared to the previous month. Elevations at the other sites increased by only 0.3-0.7 foot during the same time period. As shown in Figure 7, this difference in water level rise is consistent with increases in river stage found at the same time by Johnson (2003). The onset of fall precipitation and corresponding infiltration into the outwash aquifers in the Sammamish Basin and Lake Sammamish may have raised the water table in the upper part of the river more than in the lower river.

Vertical gradients (i_v) at the sampling sites normalize water level measurements for the depth of the mini-piezometers (Table 2). Gradients ranged from 0.012 to 0.090 foot/foot at the points where groundwater entered the riverbed. At SAM-70, the losing point, negative gradients were about an order of magnitude higher than at the gaining locations (mean = -0.24, n=3, foot/foot).

Specific conductivity and temperature

Temperature and specific conductivity can be different enough in groundwater and surface water to help distinguish gaining from losing areas in a river. Where temperature and specific conductivity are the same in surface and groundwater, the river is usually losing water to the streambed, while a difference between surface and groundwater temperature and specific conductivity usually indicates groundwater is discharging to the river. In lowland streams, groundwater is usually cooler than surface water in the summer and warmer than surface water in the winter.

The specific conductivity of groundwater in the Sammamish River area is typically higher than that in surface water. Dalton et al. (2000) and Johnson (2002) found groundwater values in private wells near the Sammamish River averaging about 200 uS/cm. The mean surface water specific conductivity at the sites observed in the current study was about 120 uS/cm.

Table 2. Depth-to-water measurements in mini-piezometers and surface water and vertical hydraulic gradients.

Site	Date	River stage (feet below top of casing)	Groundwater level (feet below top of casing)	Difference between surface water and groundwater levels (dh) (feet)	Piezometer stick-up above streambed (feet)	Piezometer depth below streambed (feet)	Piezometer depth to mid-point of perforations (dl) (feet)	Vertical hydraulic gradient (dh/dl) (feet/feet)
SAM-1	8/9/2001	1.35	1.26	0.09	2.00	5.00	4.75	0.019
SAM-1	9/20/2001	1.36	1.28	0.08	2.01		4.75	0.016
SAM-1	10/11/2001	1.16	1.08	0.08	2.08	4.92	4.67	0.016
SAM-1	11/8/2001	0.38	0.39	-0.02			4.75	-0.003
SAM-2	8/9/2001	1.28	1.16	0.12	2.03	4.97	4.72	0.025
SAM-2	9/20/2001	1.32	1.19	0.13	2.00		4.72	0.027
SAM-2	10/11/2001	1.11	1.00	0.11	2.05	4.95	4.72	0.023
SAM-2	11/8/2001	0.00	0.04	-0.04			4.72	-0.008
SAM-70	9/21/2001	0.71	2.23	-1.52	1.90	5.10	4.85	-0.313
SAM-70	10/11/2001	0.16	0.43	-0.27	1.84	5.16	4.91	-0.055
SAM-70	11/8/2001	0.61	2.21	-1.60	2.25	4.75	4.50	-0.356
SAM-85	8/21/2001	2.04	1.97	0.07	2.72	4.28	4.03	0.017
SAM-85	9/20/2001	1.57	1.51	0.06	2.56	4.44	4.19	0.014
SAM-85	10/11/2001	1.09	1.04	0.05	2.61	4.39	4.14	0.012
SAM-85	11/8/2001	0.43	0.34	0.09	2.61	4.39	4.14	0.022
SAM-95	9/20/2001	0.88	0.77	0.11	2.10	4.90	4.65	0.024
SAM-95	10/11/2001	0.40	0.31	0.09	2.10	4.90	4.65	0.019
SAM-95	11/8/2001	0.10	0.05	0.05	2.18	4.82	4.57	0.011
SAM-116	8/20/2001	1.49	1.20	0.29	2.75	4.25	4.00	0.073
SAM-116	9/21/2001	1.33	1.27	0.06	2.75	4.25	4.00	0.015
SAM-116	10/11/2001	1.08	0.91	0.17	2.75	4.25	4.00	0.043
SAM-116	11/9/2001	0.92	0.77	0.15	2.76	4.24	3.99	0.038
SAM-130	8/20/2001	1.19	1.06	0.13	1.85	4.44	4.19	0.031
SAM-130	9/20/2001	1.09	0.94	0.15	1.81	5.19	4.94	0.030
SAM-130	10/11/2001	0.92	0.79	0.13	1.82	5.18	4.93	0.026
SAM-130	11/9/2001	0.70	0.55	0.15	1.82	5.18	4.93	0.030
SAM-135	8/20/2001	1.48	1.34	0.14	2.25	4.75	4.50	0.031
SAM-135	9/21/2001	1.45	1.14	0.31	2.18	4.82	4.57	0.067
SAM-135	10/11/2001	1.27	1.10	0.17	2.18	4.82	4.57	0.037
SAM-135	11/9/2001	0.97	0.85	0.12	2.04	4.96	4.71	0.025
SAM-143	8/21/2001	1.07	1.01	0.05	2.60	4.40	4.15	0.013
SAM-143	9/21/2001	1.08	0.74	0.34	2.60	4.40	4.15	0.081
SAM-143	10/11/2001	0.85	0.61	0.23	2.60	4.40	4.15	0.056
SAM-143	11/9/2001	0.41	0.03	0.37	2.60	4.40	4.15	0.090

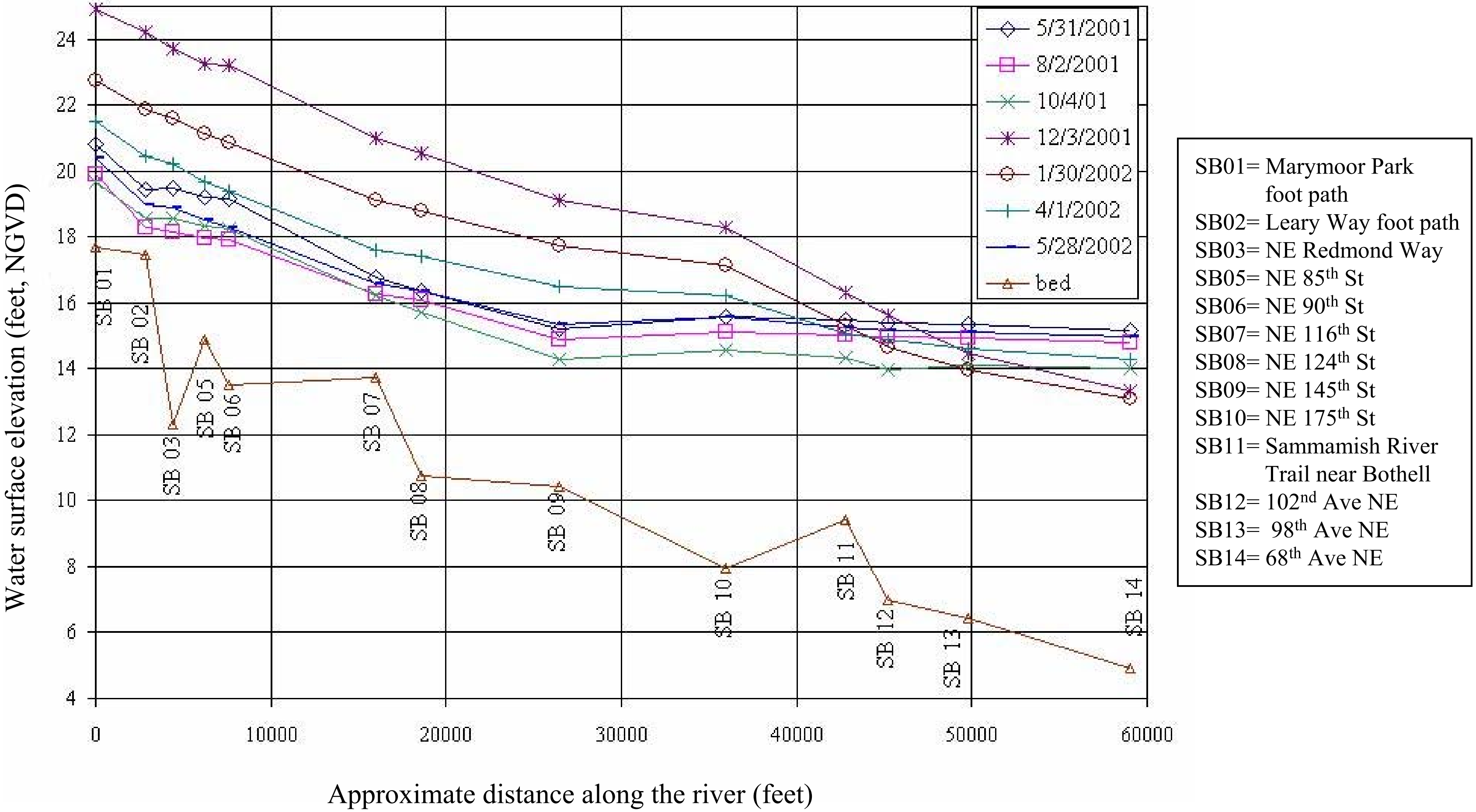

Figure 7. Sammamish River water surface profiles for May 31, 2001 through May 28, 2002 (Johnson, 2003).

As shown in Table 3, specific conductivity measurements in groundwater were consistently higher than in surface water, indicating that groundwater was discharging to the river. However, the difference between specific conductivity of surface and groundwater was lower at SAM-95 (53-72 uS/cm) than at the other sites, where the differences ranged from 94-400 uS/cm. The reason for this difference may be a lower rate of inflow at the sample site than at other sites, or the groundwater inflow may derive from a different aquifer zone with water of lower specific conductivity.

Table 3. Temperature and specific conductivity results.

Site	Date	Surface water Temperature (ºC)	Groundwater Temperature (ºC)	Temperature Difference (ºC)	Surface water Conductivity (uS/cm)	Groundwater Conductivity (uS/cm)	Conductivity Difference (uS/cm)
SAM-1	8/9/01	21.3	12.8	8.5	112	209	97
SAM-1	9/20/01	17.9	12.6	5.3	117	211	94
SAM-1	10/11/01	14.0	11.9	2.1	115	213	98
SAM-1	11/8/01	10.7	11.4	-0.7	113	213	100
SAM-2	8/9/01	22.0	13.0	9.0	116	312	196
SAM-2	9/20/01	18.3	13.1	5.2	121	323	202
SAM-2	10/11/01	13.3	12.0	1.3	160	311	151
SAM-2	11/8/01	10.5	11.6	-1.1	125	313	188
SAM-70	9/21/01	16.0	NA	NA	131	NA	NA
SAM-70	10/11/01	11.8	NA	NA	125	NA	NA
SAM-70	11/8/01	10.0	NA	NA	119	NA	NA
SAM-85	8/21/01	17.9	14.8	3.1	134	237	103
SAM-85	9/20/01	16.3	15.5	0.8	134	252	118
SAM-85	10/11/01	12.1	14.2	-2.1	125	254	129
SAM-85	11/8/01	10.2	13.0	-2.8	120	245	125
SAM-95	9/20/01	16.6	13.0	3.6	134	187	53
SAM-95	10/11/01	11.9	12.0	-0.1	121	193	72
SAM-95	11/8/01	10.2	11.3	-1.1	121	190	69
SAM-116	8/20/01	18.8	14.4	4.4	139	236	97
SAM-116	9/20/01	17.1	14.1	3.0	139	248	109
SAM-116	10/11/01	12.1	13.3	-1.2	119	250	131
SAM-116	11/9/01	9.5	11.9	-2.4	124	251	127
SAM-130	8/20/01	20.5	13.6	6.9	142	446	304
SAM-130	9/20/01	17.0	12.9	4.1	145	543	398
SAM-130	10/11/01	12.0	12.0	0.0	124	522	398
SAM-130	11/9/01	9.6	11.9	-2.3	127	413	286
SAM-135	8/20/01	20.0	13.2	6.8	154	278	124
SAM-135	9/20/01	17.0	12.2	4.8	157	265	108
SAM-135	10/11/01	12.1	11.8	0.3	122	265	143
SAM-135	11/9/01	9.7	11.0	-1.3	128	266	138
SAM-143	8/21/01	17.9	NA	NA	148	NA	NA
SAM-143	9/21/01	15.6	NA	NA	148	NA	NA
SAM-143	10/11/01	12.1	NA	NA	12.1	NA	NA
SAM-143	11/9/01	10.3	11.9	-1.6	128	245	117

The difference in specific conductivity between surface and groundwater at SAM-130 was about 200 uS/cm greater than at the other sites as shown in Figure 8. The low pH of the Tukwila muck soils along the river in the area may cause more ions to dissolve in the groundwater and thereby increase the conductivity (USDA Soil Conservation Service, 1973). Agricultural activities along that stretch of the river also may play a role, because some leaching of ions occurs even when best management practices are implemented. Ecology observed discharging drains near agricultural areas on both sides of the river during the study. Input from these drains would tend to increase the specific conductivity of the river.

There appeared to be a general trend toward increasing surface water conductivity from the upper end of the river (SAM-1 and SAM-2) to the lower end of the study area (SAM-143). This trend is consistent with the theory that the river is mainly gaining in the study area.

Groundwater temperatures were lower than surface water temperatures in August and September at all mini-piezometers, indicating groundwater discharge to the river during these low-flow months (Table 3). However, as expected, differences were muted in October and November, because air temperatures had decreased to the range of groundwater temperature. Also, as expected, groundwater temperatures were slightly warmer than those in the surface water in November.

Temperature in the river bottom

Figure 9 shows hourly temperature readings from data loggers at the base of three piezometers in the river. The furthest upstream site, SAM-1, is downstream of the outlet of Lake Sammamish which is dominated in the summer by warm water flowing from the surface of the lake. SAM-116 and SAM-130 are located about three miles downstream of Bear Creek and an unnamed tributary which together add about 10% to the flow of the river and are cooler than the river upstream (Johnson, 2001). A subsurface inflow of unknown magnitude is also presumed to enter the river from the Bear Creek Basin and have a cooling effect. During this study, a 2ºC decrease in temperature occurred between the upstream site (SAM-1) and the two downstream sites (SAM-116 and SAM-130).

Figure 9 also illustrates the contrast during the summer between the warm surface water and cooler groundwater as noted in the mini-piezometer data above. The similarity in winter (November) groundwater and surface water is also illustrated in Figure 9.

Conclusions

Groundwater appears to be discharging into the Sammamish River at eight of nine locations based on water level, specific conductivity, and temperature comparisons between in-stream mini-piezometers and the river. An increasing trend in specific conductivity in the river between the upstream and downstream ends of the study area also indicates the input of higher conductivity groundwater to the river.

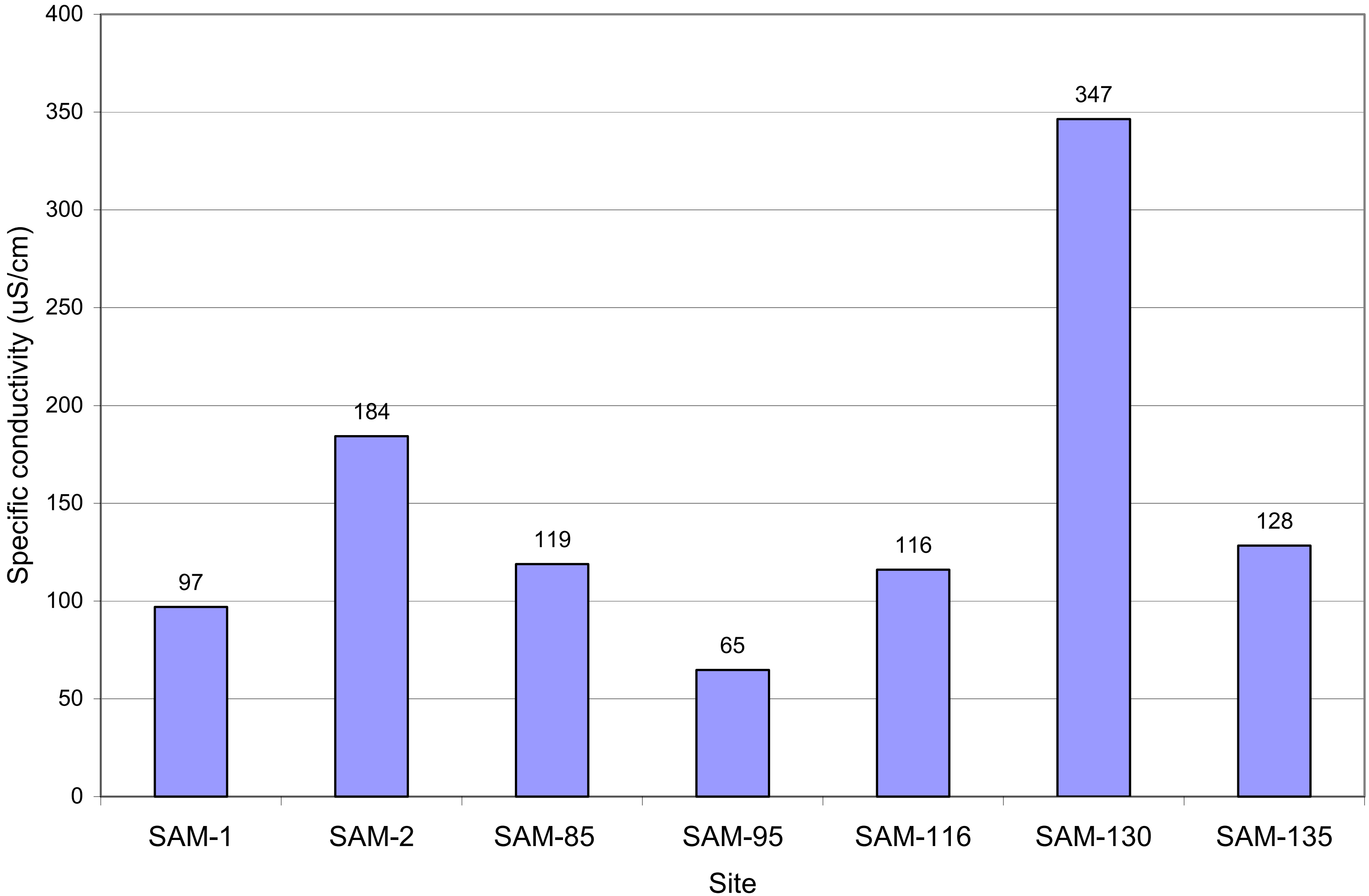

Figure 8. Mean differences between specific conductivity in surface water and groundwater.

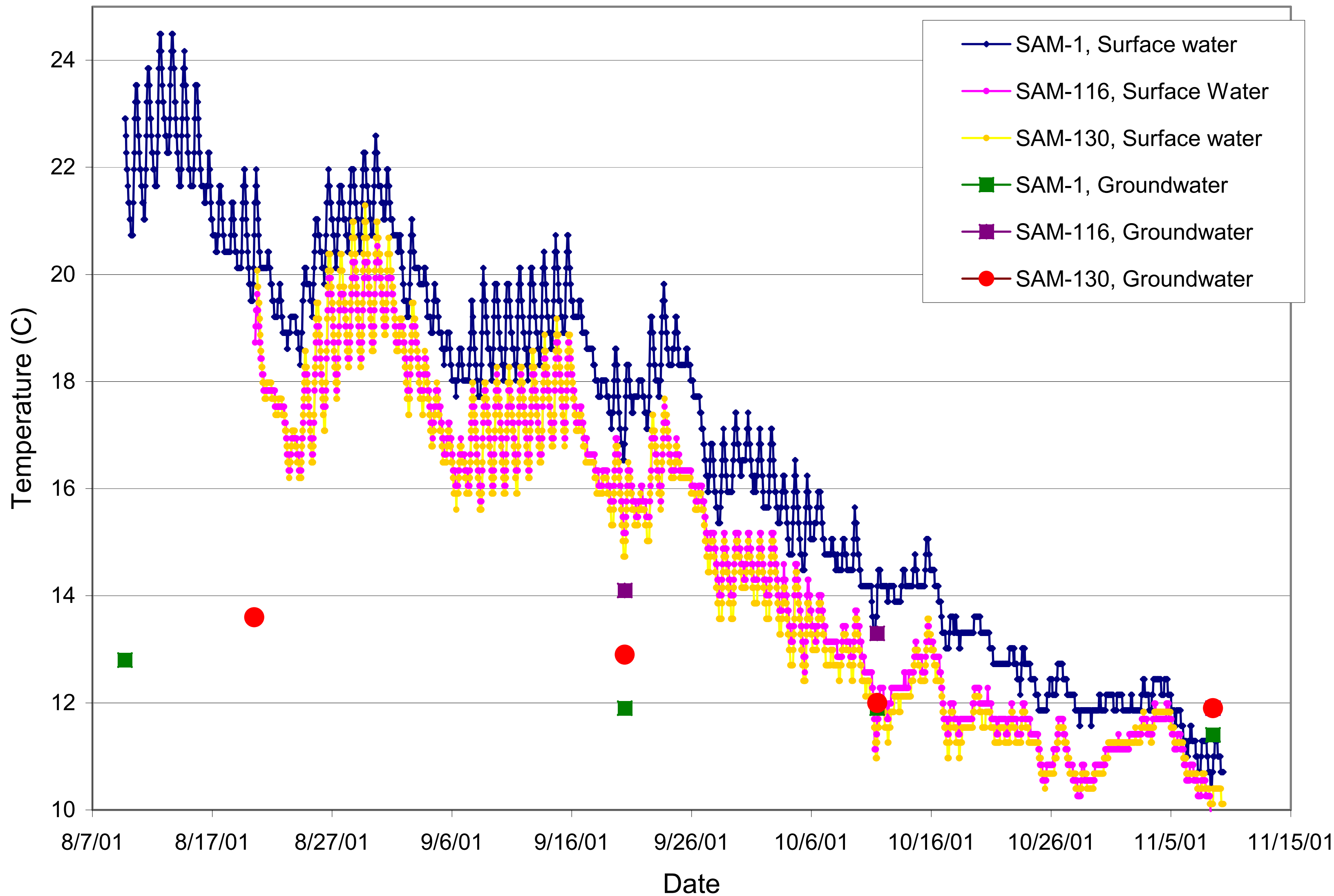

Figure 9. Temperature measurements outside mini-piezometers (near the sediment/water interface) and in groundwater at three locations.

In contrast, surface water appears to be leaving the river and entering the aquifer at SAM-70 (river mile 20.2) according to mini-piezometer measurements. This contradicts previous assumptions that the river receives subsurface flow from the Bear Creek alluvial aquifer in this area. Elevated specific conductivity values in groundwater at SAM-130 (RM 17.2) may be related to local natural soil conditions or to nearby agriculture but do not necessarily indicate poor management. Tile drains observed discharging along the river also indicate an unknown flow to the river, perhaps more substantial than groundwater. At SAM-95, groundwater specific conductivity values were about 25% lower than those at other sites, possibly due to lower groundwater flow or to inflow from a different aquifer than indicated at the other sites.

During the low-flow months of late summer and early fall, groundwater temperatures were 1-9ºC cooler than surface water at all sites. Winter measurements indicated similar to slightly warmer temperatures in groundwater than in surface water.
*
Data from temperature loggers indicate that in the fall the temperature at the river bottom along the bank cools by about 2ºC between the bridge at Marymoor Park (RM 20.9) and downstream of Bear Creek and the unnamed tributary inputs (RM 17.2 and 17.7). This is consistent with previous studies showing cooling below Bear Creek and the unnamed tributaries.

Recommendations

Information from historical seepage studies on the Sammamish River could be used to compare areas of inflow and outflow to those found in this study. A follow-up investigation could verify that surface water is recharging the aquifer at SAM-70 (RM 20.2) in the fall and, if so, determine the extent and seasonal variation of this apparent losing reach.

Flow directions observed at points along the Sammamish River in this study could be compared to groundwater flow directions observed in newly installed King County Department of Natural Resources & Parks (KC DNRP) monitoring wells. Where more detailed information is needed for the on-going KC DNRP study, mini-piezometers could be used to evaluate gaining and losing areas in other Sammamish River segments. In particular, the stream segment identified in the U.S. Army Corps of Engineers study as a likely area of significant groundwater recharge downstream of this study area should be sampled. Boat access may be easier than bank access during low-flow investigations in downstream reaches.

Additional withdrawals from shallow aquifers in the Sammamish River Valley are not advisable because of the cooling influence of shallow groundwater flowing into the river during the summer.

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Appendix

Standard Operating Procedures for Temperature, Specific Conductivity, and Water Level Measurements

Temperature and specific conductivity

A Geotech WTW multimeter was used for all temperature and specific conductivity measurements according to the following procedure.

- Calibrate the Geotech WTW multimeter and probes on the day of sampling and
  - For temperature, at least one time during the two-month study, compare the Geotech readings to those of an NIST mercury thermometer through the range of 0-25ºC in 5º intervals. Readings within 0.2ºC are acceptable.
  - For specific conductivity, calibrate according to the WTW User's Manual with 1,413 uS/cm standard. Following calibration, test a sample of a known standard in the range of the water to be sampled. Results within 5% are acceptable.
- When sampling surface water near a mini-piezometer, allow the probe to equilibrate in the river for at least three minutes at about six inches depth. When temperature is not changing more than 0.2ºC and specific conductivity not more than 5 uS/cm, record the measurements.
- When sampling mini-piezometer discharge, monitor temperature and specific conductivity output in a 500 ml polyethylene bottle with the probe submerged. When purging is complete (at least 10 minutes) and temperature and specific conductivity readings are stable, as described for surface water above, record the temperature and specific conductivity.

Water level measurements

Mini-piezometer sampling methods

On the day of installation, the mini-piezometers were allowed to equilibrate after installation and development. When the water inside the piezometer had equilibrated (on the order of 10-15 minutes), the depth-to-water inside the piezometer was measured using an electrical tape. The stream stage was measured by extending an engineer's measuring tape along the outside of the piezometer pipe from the top of the pipe to the river surface. Both measurements were made to the nearest 0.01 foot. After the initial sampling event, the same procedure was used as on the first day excluding the initial pause for equilibration.

A few of the piezometers were not perpendicular to the streambed. In these cases, the depth-to-water measurements were corrected using trigonometric calculations to find the true depth-to-water.